Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**
4. TITLE AND SUBTITLE **IR Photonic Bandgap Fibers for Missile Defense**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,4555 Overlook Avenue SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**2**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

IR Photonic Bandgap Fibers for Missile Defense

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The Application: IR-transmitting fibers fabricated at the Naval Research Laboratory (NRL) have low optical loss (~0.2 dB/m) and have been successfully used in aircraft missile defense system demonstrations for the 2 to 5 µm region to replace bulk optics connecting the laser to the jam head as well as being "wired" inside the jam head.[1] These conventional, solid-core fibers result in significant weight reduction. They reduce system size and complexity as well as cost of both installation and maintenance, and are capable of laser power input typical of current systems. However, advanced infrared threats require much higher laser power, which these solid-core fibers cannot tolerate.

The Solution: A new type of fiber, called the hollow-core photonic bandgap (or HC-PBG) fiber, has been developed and demonstrated using silica glass. These fibers consist of a hollow air core, surrounded by an ordered series of holes (formed by hollow tubes) and then an outer solid glass protective clad (Fig. 4). Theoretical predictions show that greater than 99% of the light transmits through air, with the so-called "microstructured" region around the core serving as a type of Bragg grating to maintain propagation at specific ranges of wavelengths that are determined by the small holes' spacing and diameter.

HC-PBG fibers are very attractive for the very high laser power transmission needed in missile defense systems currently under development to defeat advanced IR threats. However, even with only 1% of the light interacting with the glass, the losses for silica HC-PBG fibers are inherently too high to make them useful in the infrared. At NRL we are developing PBG fibers based on IR-transmitting materials by leveraging in-house expertise with materials purification and fabrication techniques.

Design and Fabrication: We have designed PBG fiber structures by solving Maxwell's equations in a periodic structure as an eigenvalue problem with the electromagnetic field expanded in a basis of plane waves.[2] One example of a structure modeled for transmission at around 4 µm using a sulfide-based glass consists of a hole size and spacing in the micro-structured region of 3.2 and 6.4 µm, respectively, and the air fill factor in that region is 89%. By adjusting the microstructure hole size, spacing, and fill factor, different wavelength regions for transmission can be obtained. The PBG fiber produces a uniform Gaussian modal output,[2] providing a low divergence output needed for systems that are increasingly requiring high brightness and spatial quality.

High purity glasses have been fabricated and made into high precision tubes using NRL's extrusion technology. These tubes are then stretched and stacked into the appropriate geometry (Fig. 5), to make a preform that also has an outer glass surrounding the tubes to keep them fixed and to provide mechanical strength. The whole assembly is then drawn into HC-PBG fiber on a draw tower with special adaptations for this purpose, and within a clean room environment. Figure 6 shows a stacked preform and preliminary fibers made from sulfide-based materials.

NRL has confirmed that HC-PBG fibers have negligible loss upon bending. This was demonstrated by no change in output from HC-PBG fiber with and without 11 half-inch bends around a mandrel. These remarkable results show the flexibility and utility of these fibers for practical systems where they may need to be routed through tight spaces.

Summary: Future missile defense systems currently under development to protect military or civilian aircraft require higher output power due to advanced infrared threats. For the more advanced systems, we are developing infrared-transmitting HC-PBG fibers, which are capable of at least 100 times more power handling capability due to 99% of the power being transmitted through the hollow core. They possess a

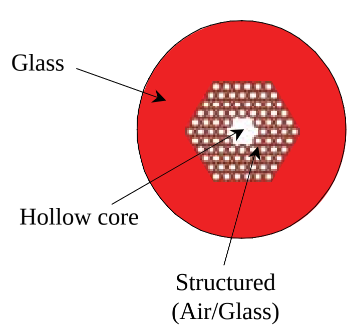

FIGURE 4
Endface view of the hollow core photonic bandgap fiber (HC-PBG) showing the microstructured region surrounding the core, as well as the protective outer layer of glass.

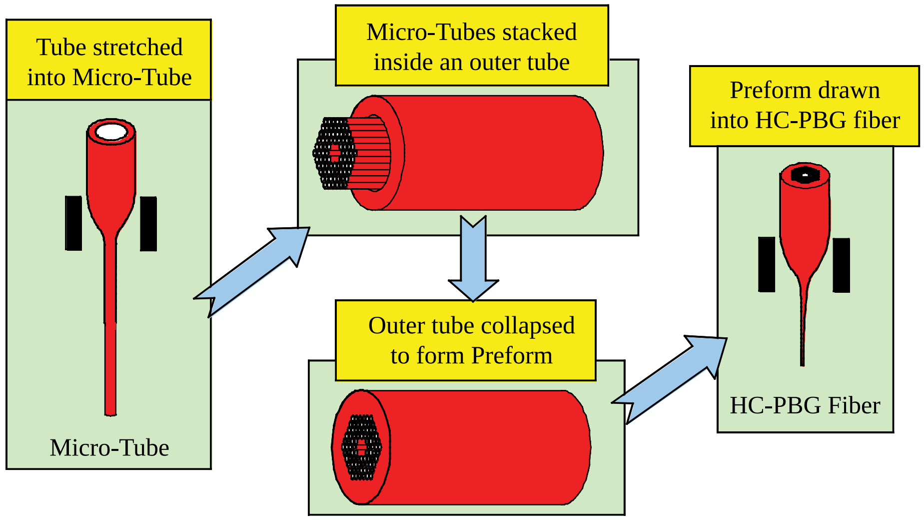

FIGURE 5
Tube stacking to make preform and drawing of HC-PBG fiber.

low divergence output, and furthermore, antireflection coatings are not needed. Fibers have been designed for transmission within the mid-IR (2 to 5 μm) region. High purity glasses have been fabricated using NRL's world class facilities, and novel extrusion technology has been developed to make microstructured preforms that have been drawn into HC-PBG fibers. The fibers exhibit high strengths comparable to their solid core counterparts. The availability of these fibers will impact next generation missile defense systems using ultra-high-power IR lasers.

[Sponsored by NRL]

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[1] L.E. Busse, J.S. Sanghera, I.D. Aggarwal, A. Carbonaro, and T.H. Evans, "Infrared-Transmitting Fibers for Advanced IRCM System Demonstrations," Proc. 39th MSS Specialty Group Meeting on Infrared Countermeasures, Volume I, Laurel, MD, 1-3 May 2001.

[2] L.B. Shaw, J.S. Sanghera, I.D. Aggarwal, and F.H. Kung, "As-S and As-Se Based Photonic Bandgap Fiber for IR Laser Transmission," *Opt. Express* **11** (25), 3455-3460 (2003).

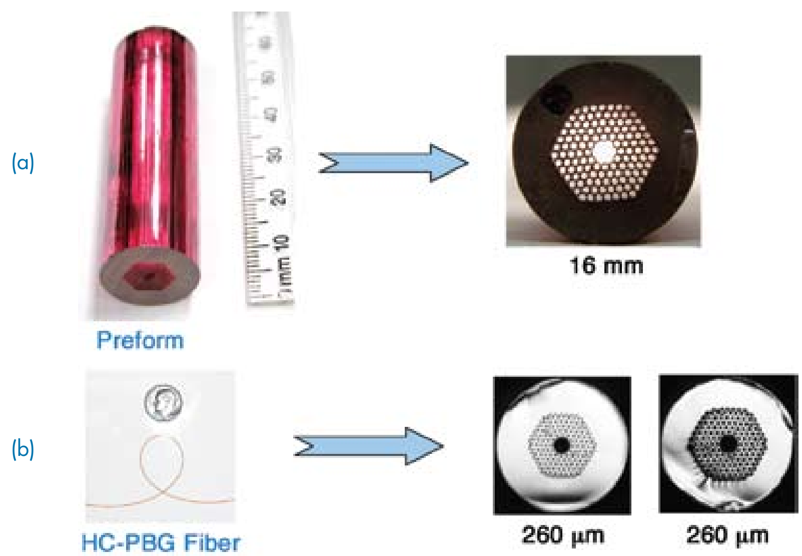

FIGURE 6
(a) Microstructure preform and (b) HC-PBG fiber made from IR transmitting sulfide glass.